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USING A FLEXIBLE ELECTRIC HEATING ELEMENT AS A HEATING DEVICE FOR BIOGAS REACTORS

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Abstract. *The article is devoted to the issue of research on the influence of the mass-dimensional characteristics of the combined mixing and electric heating system on the amount of heat released during its cooling. The main hypothesis of the work is that due to the use of the amount of heat accumulated by the combined system of mixing and electric heating during operation, it will be possible to save energy for heating the substance in the reactors. Savings arise due to an increase in the duration between the cycles of turning on the heating device. The article presents the results of numerical studies at different temperatures of the electric heating element, reactor volumes, and mass-size characteristics of the combined system.*

The dependence of the change in the amount released during cooling of the combined mixing and electric heating system on the mass and dimensional characteristics of the system, the volume of the biogas reactor and the temperature of the heating element was established.

The obtained results can be used in the design and construction of systems of mixing and electric heating of the substrate in biogas reactors and combined with an automatic control system. The established dependencies increase the profitability of biogas production and reduce the cost of 1 m^3 of generated gas, due to the reduction of energy costs for maintaining the temperature and hydrodynamic conditions necessary for anaerobic fermentation to proceed.

Keywords: energy, heating, mixing, flexible electric heater, biogas reactor, thermodynamic equilibrium.

Introduction. Biogas technologies are becoming increasingly widespread in the energy sector of countries around the world. After all, it is in biogas reactors that fermentation of organic waste takes place and biogas is obtained. Various types of organic waste are fermented in biogas reactors, the most common of which are: livestock excrement, litter in animal housing, feathers and poultry waste, agricultural products, etc.

Agricultural waste, animal feces, fluff, manure, feathers, fats and other waste from livestock complexes are biological mass, which by its composition is most effective for fermentation in special tanks – biogas reactors without access to oxygen. The composition of livestock waste primarily depends on the age and type of animals, the composition of their diet and methods of maintenance.

The type of raw material fermented in a biogas reactor affects the concentration of methane and other gases in the resulting volume of biogas.

It is worth noting that for the stability of the fermentation of the substrate, a necessary condition is the maintenance of the set temperature and mixing of the substance [1, 2].

According to the conditions of the anaerobic fermentation process, biogas is released in three temperature modes [3 – 5]: psychrophilic – 15-20 ^{0}C, mesophilic – 33-37 ^{0}C, thermophilic – 55-57 ^{0}C.

The role of mixing is to prevent the formation of sediment and the destruction of the floating crust, as well as the release of gas bubbles from the volume of raw materials [6].

The need to mix the raw materials being fermented in the biogas reactor is also related to ensuring uniform distribution of the raw materials throughout the reactor volume.

Careful mixing contributes to the growth of bacterial colonies, which in turn increases the biogas yield and increases the profitability of the biogas plant.

Biogas plants are placed outdoors, so maintaining a stable temperature plays one of the important functions while consuming a large amount of energy [6, 7]. In the literature of foreign and domestic scientists, there are various systems for mixing and heating raw materials [1, 6, 9].

One of the most common systems for heating reactors is to use a coil placed on the outer wall of the reactor through which heated water is pumped. The disadvantage of this method is the need for additional equipment for pumping heated water, the construction of an additional boiler room and a heat supply main. The presence of a heat supply main from the boiler room to the biogas reactor leads to additional heat losses to the atmosphere.

The works [10-15] give the results of theoretical and experimental studies that indicate the effectiveness of the combination of the mixing system and electric heating.

Considering the above, it is necessary to investigate the influence of the mass-dimensional characteristics of the combined system of mixing and electric heating on the amount of heat released during its cooling.

To date, the situation on the energy market remains unstable, therefore the issue of increasing the energy efficiency of renewable energy sources is an urgent and important task.

Purpose. Study of the influence of the mass-dimensional characteristics of the combined system of mixing and electric heating on the amount of heat released during its cooling.

Materials and methods. The main hypothesis is that the use of the amount of heat released during the cooling of the metal structure of the combined mixing and heating system will allow to save energy for heating the substance in the tanks. It is planned to obtain savings due to an increase in the duration between the cycles of turning on the heating device.

Numerical studies use the proposed combined system of mixing and electric heating, which is shown in Fig. 1.

According to fig. 1 heating element is located directly in the blades and shaft of the mechanical mixer. When the current passes through the spiral of the heating element, heat is released, and accordingly, the metal structure of the stirring device is heated.

A flexible electric heating element, the temperature of which is even $T_3 = 60\ °C$ is in direct contact with the metal structure of the stirring device. As a result, the temperature of the heating element and metal structure (T_2) of the stirring device are the same ($T_2 = T_3\ °C$).

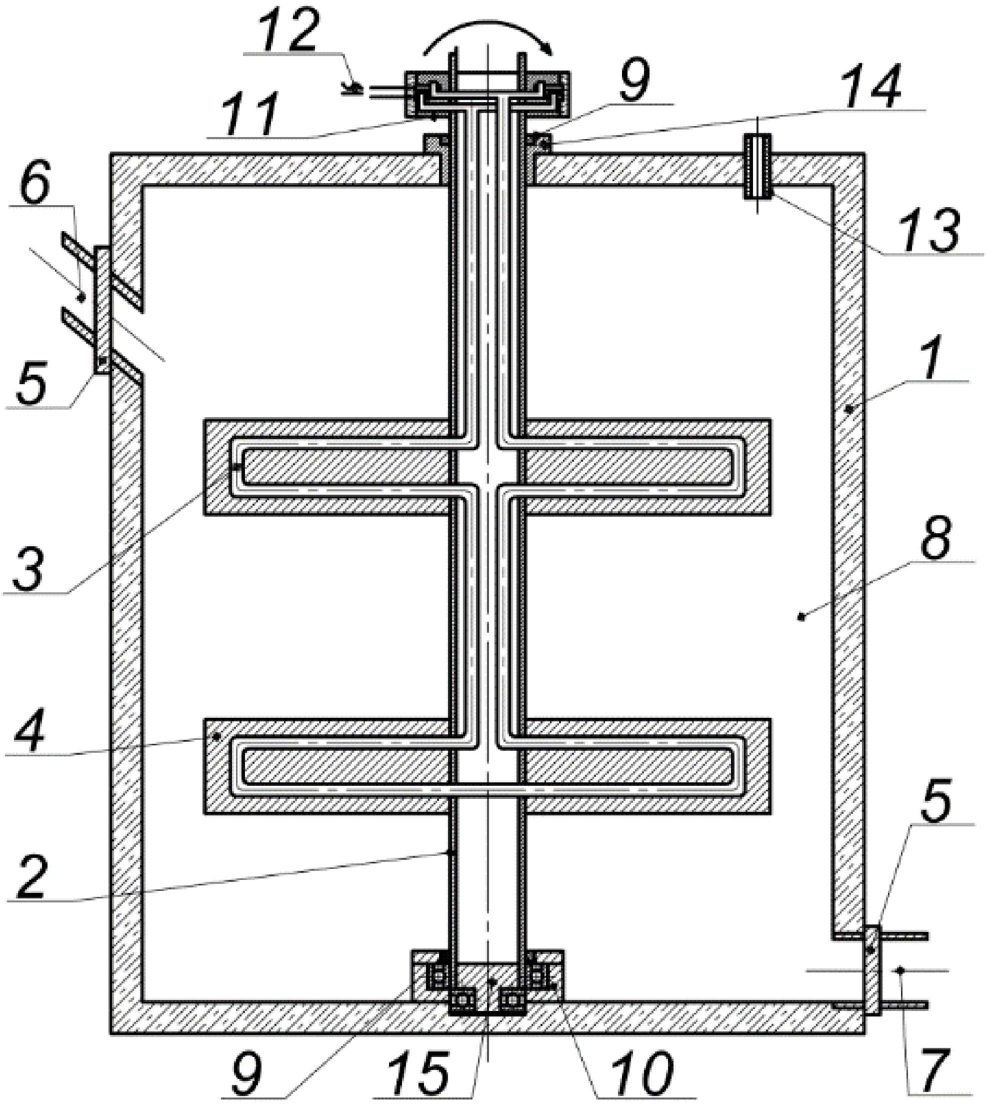

Fig. 1. Longitudinal section of the biogas reactor with the proposed design of the combined system of mixing and heating the substrate using a flexible electric heating element: 1 – tank; 2 – hollow shaft; 3 – flexible electric heater; 4 – blade; 5 – slide latch; 6 – download channel; 7 – discharge channel; 8 – biomass; 9 – stuffing box seal; 10 – support with bearings; 11 – explosion-proof sliding contacts; 12 – power source of direct or alternating electric current; 13 – biogas outlet fitting; 14 – sleeve; 15 – trunnion.

The combined mixing and heating system is immersed in the raw material volume. Because, according to the law of thermodynamic equilibrium, when two environments with different temperatures are in direct contact, a process of heat transfer takes place between them, as a result of which their temperatures are equalized.

Mathematically, this process is described by the dependence:

$$T_{eq} = \frac{m_1 \cdot c_1 \cdot T_1 + m_2 \cdot c_2 \cdot T_2}{m_1 \cdot c_1 + m_2 \cdot c_2}, \quad (1)$$

where m_1 – the mass of raw materials in the biogas reactor, kg;

c_1 – specific heat capacity of raw materials, $J/(kg \cdot °C)$;

c_2 – specific heat capacity of the material from which the combined system is made, $J/(kg \cdot °C)$;

T_1 – raw material temperature, ^{0}C;

T_2 – temperature of the combined mixing and electric heating system, ^{0}C;

m_2 – mass of the combined mixing and electric heating system, kg.

The mass of the combined mixing and heating system is found by the formula:

$$m_2 = m_p + m_s, \quad (2)$$

where m_p, m_s – mass of paddles and shaft of the mixing device, kg.

We determine the mass of the paddles based on the dependence:

$$m_p = \rho_p \cdot b_p \cdot h_p \cdot \delta_p \cdot z, \quad (3)$$

where z – number of paddles, pcs;

ρ_p – specific density of the material from which the blade is made, kg/m^3;

h_p – paddle height, m;

b_p – paddle width, m;

δ_p – paddle thickness, m.

The mass of the shaft is determined from the dependence:

$$m_s = \rho_s \cdot l_s \cdot \frac{\pi}{4} \cdot \left(D_s^2 - (D - 2 \cdot \delta_s)^2\right), \quad (4)$$

where ρ_s – specific density of the material from which the shaft is made, kg/m^3;

l_s – shaft length, m;

D_s – outer diameter of the shaft, m;

δ_s – shaft wall thickness, m.

During the cooling of the combined mixing and electric heating system, heat is released (Q_{cool}).

Mathematically, this process is described by a dependency:

$$Q_{cool} = c_2 \cdot m_2 \cdot (T_2 - T_1) \quad (5)$$

According to the purpose of the work, numerical studies were carried out for tanks with a volume of 50 to 200 liters, under the condition of fermentation of raw materials at a mesophilic temperature regime ($T_1 = 35\ °C$).

With an increase in the geometric dimensions of the biogas reactor, there is an increase in the mass-dimensional characteristics of the combined mixing and electric heating system.

Taking into account the above, in the numerical study, depending on the volume of the biogas reactor, the appropriate mass of the combined system was used, the value of which lies in the range from 17 to 42 kg.

The combined system is made of stainless steel with appropriate physical and chemical parameters. Combined system temperature (T_3), was in the range from 35 to 60 $°C$ for each volume of the biogas reactor.

The final condition of the numerical studies is: establishing the balanced temperature of the raw materials in the reactor and the combined system at the mark 35 $°C$.

Results and discussion. The result of the conducted research is obtaining graphical dependences of the temperature change of the combined system and the value of the released heat (Fig. 2).

From the graphical dependences (Fig. 2) it can be seen that the combined system is heated to 60 $°C$, accumulates in its mass from 210 to 520 kJ of thermal energy.

As a result of conducting numerical studies and analysis of graphical results (Fig. 2), it was found that a decrease in the heating temperature (T_3), leads to a decrease in the accumulation of thermal energy in the metal structure of the combined mixing and electric heating system. At the heating temperature (T_3), at the same fermentation temperature of the substrate (T_1), the amount of heat released during cooling of the combined system $Q_{cool} \approx 0$ kJ.

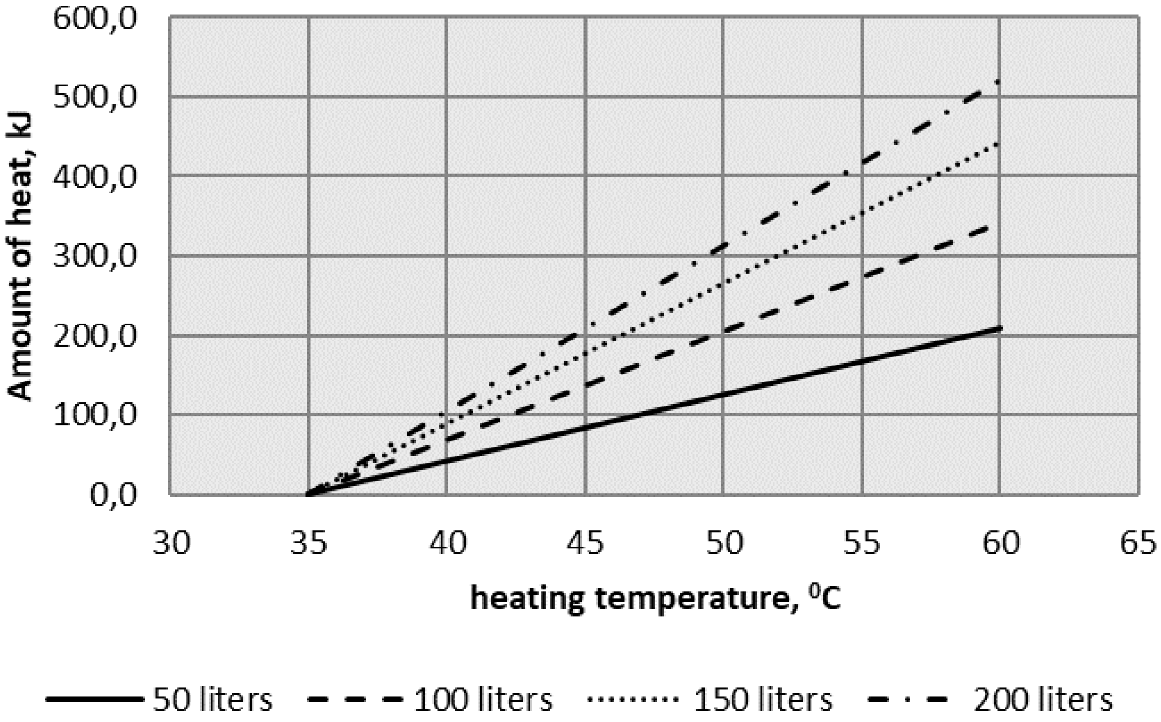

Fig. 2. Results of a numerical study of heat release during cooling of the combined mixing system and electric heating.

Based on the obtained results, a further direction of scientific and practical research aimed at the creation and research of energy-efficient control systems for heating devices, metal construction materials with different physical and chemical parameters, and schemes for combining mixing and heating processes has been established.

Conclusions. Numerical studies were carried out at different temperatures of the heating electric element and reactor volumes in order to determine the amount of released heat during cooling of the combined mixing and heating system.

The dependence of the change in the amount of heat released during cooling of the combined system on the volume of the biogas reactor was revealed.

The use of the proposed combined mixing and heating system in combination with an automatic control system will allow to create a uniform distribution of heat throughout the volume of the biogas reactor, as well as to reduce energy costs and increase the productivity of the biogas plant.

The established dependencies can be used at the design and operation stages of biogas reactors.

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ВИКОРИСТАННЯ ГНУЧКОГО ЕЛЕКТРИЧНОГО НАГРІВАЛЬНОГО ЕЛЕМЕНТУ У ЯКОСТІ НАГРІВАЛЬНОГО ПРИСТРОЮ ДЛЯ БІОГАЗОВИХ РЕАКТОРІВ

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Анотація: *Стаття присвячена питанню дослідження впливу масогабаритних характеристик комбінованої системи змішування та електричного підігріву на кількість теплоти, що виділяється при її охолодженні. Основна гіпотеза роботи полягає у тому, що за рахунок використання кількості теплоти накопиченої комбінованою системою змішування та електричного підігріву під час роботи, дозволить заощаджувати енергію для нагріву речовини у реакторах. Економія виникає за рахунок збільшення тривалості між циклами вмикання опалювального приладу. У статті наведені результати чисельних досліджень за різних температур електричного нагрівального елементу, об'ємів реакторів та масогабаритних характеристик комбінованої системи.*

Встановлено залежності зміни кількості виділеної під час охолодження комбінованої системи перемішування та електричного підігріву від масо-габаритних характеристик системи, об'єму біогазового реактора та температури нагрівального елементу.

Отримані результати можуть бути використані при проектуванні та побудові систем перемішування та електричного підігріву субстрату у біогазових реакторах та поєднані їх з системою автоматичного керування. Встановлені *залежності підвищують рентабельність біогазового виробництва та знижують вартість 1 м^3 утвореного газу, за рахунок зменшення енергетичних витрат на підтримку температурних та гідродинамічних умов необхідних для протікання анаеробного бродіння.*

Ключові слова: ***енергія, підігрів, перемішування, гнучкий електричний підігрівач, біогазовий реактор, термодинамічна рівновага***